BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
H03M 13/00

A1

(11) International Publication Number: WO 98/48517

(43) International Publication Date: 29 October 1998 (29.10.98)

(21) International Application Number: PCT/US98/07348

(22) International Filing Date: 15 April 1998 (15.04.98)

(30) Priority Data:
08/845,095 21 April 1997 (21.04.97) US

(71) Applicant: GENERAL ELECTRIC COMPANY [US/US]; 1 River Road, Schenectady, NY 12345 (US).

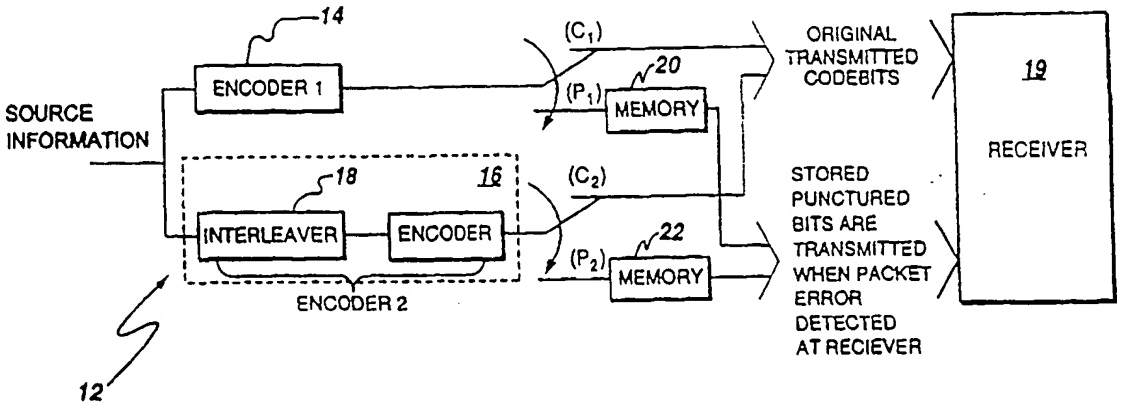
(72) Inventor: ROSS, John, Anderson, Fergus; 1109 Sumner Avenue, Schenectady, NY 12309 (US).

(74) Agents: STECKLER, Henry, I. et al.; General Electric Company, 3135 Easton Turnpike W3C, Fairfield, CT 06431 (US).

(81) Designated States: BR, CN, IL, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: TURBO–CODING WITH STAGED DATA TRANSMISSION AND PROCESSING



(57) Abstract

Turbo–coding in a communications system involves coding/decoding information in stages in order to avoid retransmission of a full L–bit packet upon occurrence of a packet error. In addition to a set of code bits generated by an encoder using a turbo–coding scheme, a punctured set of code bits is generated and stored in transmitter memory. The original set of code bits is transmitted as an L–bit data packet to a receiver which stores received data samples corresponding to the original set of code bits. The receiver decodes the data packet using a turbo–decoder and determines whether the data packet has been received in error. If so, the received data samples are maintained in memory, and a request for more information is made. Some or all of the punctured information is then forwarded from the transmitter to the receiver. A second stage of turbo–decoding combines the new data samples with the stored original received data samples such that there is a high likelihood that decoding is correct at this point, but additional stages of decoding may be used.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

TURBO-CODING WITH STAGED DATA TRANSMISSION AND PROCESSING

BACKGROUND OF THE INVENTION

The present invention relates generally to coding in communications systems and, more particularly, to turbo-coding information in stages.

Turbo-coding is known in the art as another term for parallel concatenated convolutional coding. More specifically, turbo-coding involves encoding an information sequence twice, the second encoding being performed after a random interleaving of the information sequence. Decoding is performed iteratively, and the result is reliable communication.

In many communications systems, data is transmitted in L-bit packets, where L is typically on the order of between ten and several hundred. If the receiver determines that the packet has been received in error, there may be a request to retransmit the information, referred to as an automatic repeat request (ARQ). Disadvantageously, this results in the transmission of a total of 2L bits.

Accordingly, it is desirable to provide a method and apparatus for turbo-coding which does not require a full L-bit packet to be retransmitted upon occurrence of a packet error.

SUMMARY OF THE INVENTION

A method and apparatus for turbo-coding stages of information in a communications system avoids retransmission of a full L-bit packet upon occurrence of a packet error. In accordance therewith, in addition to a set of code bits generated by an encoder using a turbo-coding scheme, a punctured set of code bits is generated and stored in transmitter memory. The original set of code bits is transmitted as an L-bit data packet, via a channel, to a receiver which stores the received data samples corresponding to the original set of code bits. The receiver decodes the data packet using a turbo-

decoder and determines whether the data packet has been received in error. If so, the received data samples are maintained in memory, and a request for more information is made. Some or all of the punctured information is then forwarded from the transmitter, via the channel, to the receiver. A second stage of turbo-decoding combines the new (i.e., punctured) data samples with the stored original received data samples. Decoding is likely to be correct at this point. However, it may be desirable to have three or more transmission stages of decoding, depending upon the application.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram illustrating a turbo-coding scheme with staged information transmission according to an embodiment of the present invention;

FIG. 2 is a block diagram illustrating turbo-coding with staged information transmission using rate 1/3 with systematic encoders according to an embodiment of the present invention;

FIG. 3 is a block diagram illustrating a staged decoder according to an embodiment of the present invention;

FIG. 4 is a flow chart illustrating staged information turbo-coding, i.e., at the transmitter, according to an embodiment of the present invention; and

FIG. 5 is a flow chart illustrating stage information turbo-decoding according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 illustrates a turbo-coding scheme with staged information transmission according to an embodiment of the present invention. In FIG. 1, a turbo encoder 12 encodes source information using a parallel concatenation of two convolutional codes in encoder 14 and in encoder 16, typically referred to in the art as Encoder 1 and Encoder 2, respectively. The second encoder, encoder 16, performs the second encoding after random interleaving in an interleaver 18.

The code bits C1 and C2 are transmitted via a channel to a receiver 19. A set of data samples corresponding to the original

transmitted code bits C1 and C2 from encoder 16 and encoder 18, respectively, are received by receiver 19 and stored in receiver memory. A punctured set of code bits P1 and P2, respectively, corresponding to code bits C1 and C2, respectively, is also generated by encoder 12 and stored in transmitter memory 20 and memory 22, respectively.

As known in the art, an encoder applies a puncturing process to a convolutional code by deleting some output bits according to a predetermined puncturing pattern in order to increase the rate of the resulting code. The associated decoder in receiver 19 includes a corresponding depuncturing function which involves inserting a neutral value for each known punctured bit. The size of the punctured set of code bits is determined by the bandwidth, power, and retransmission frequency of the system.

Receiver 19 decodes the data by turbo-decoding and determines whether the packet has been received in error. If so, then the received data samples corresponding to code bits C1 and C2 are maintained in memory. The receiver makes a request for more information, whereby some or all of the stored punctured bits are transmitted, via the channel, to the receiver. A second stage of turbo-decoding is performed, combining the data samples corresponding to punctured code bits P1 and P2 with the original received data samples corresponding to code bits C1 and C2. Advantageously, it is highly likely that decoding is correct at this point, resulting in highly reliable communication. However, depending upon the application, three or more transmission stages of turbo-decoding may be desirable.

Turbo-coding commonly involves the use of systematic convolutional codes for which input bits appear directly in the code output. To increase the rate of such a code, another form of puncturing may be applied wherein only one copy of the systematic bits is transmitted, which copy is used by all convolutional decoders in the turbo-decoding process. The staged transmission process described hereinabove may be applied to this form of puncturing as well. In particular, if a packet is received in error, a retransmission of

the systematic bits is requested with the newly received samples applied to one or more convolutional decoders of the turbo-decoding algorithm.

FIG. 2 illustrates an example of turbo-decoding of a systematic code with staged information transmission. In this example, a rate 1/3 turbo code is created by transmitting the full code output of a rate 1/2 systematic convolutional encoder 24 operating on the original input sequence while transmitting only the parity bits of a second systematic convolutional encoder 26, also rate 1/2, operating on an interleaved copy of the input sequence. At a receiver 29, the received data samples corresponding to the systematic bits are used for both of the convolutional decoding components of the turbo code. The receiver requests a second copy of the systematic bits via memory 30 only if the first attempt at decoding results in a detected packet error. The received data samples corresponding to the second copy of the systematic bits is used for the second convolutional decoder component. Advantageously, the newly requested information is only 1/3 of the number of transmitted bits required in the classical automatic repeat request (ARQ) scheme.

FIG. 3 illustrates a staged turbo decoder 40 in a receiver according to an embodiment of the present invention. The input to decoder 40 is controlled by an input data selector 42. The received data samples corresponding to the transmitted code bits are copied into memory 44 in the first stage of transmission and are used in each iteration in the turbo decoding process. Memory 44 also allows systematic information that is common to encoder 1 and encoder 2 (FIGs. 1 and 2) to be transmitted only once in the first stage of turbo decoding. In the first stage of decoding, the data selector chooses A when the information has been punctured and chooses B when the received data samples are available. Memory 44 is addressed by the non-interleaving sequence when encoder 1 data is processed and by the interleaving sequence when encoder 2 data is processed.

After the first stage of turbo-decoding, a packet error detection mechanism 50 determines whether the data was received correctly. An exemplary packet error detection mechanism

comprises a well-known 16-bit cyclic redundancy check (CRC) code. As described hereinabove, if a packet error is detected, a request for transmission of information previously punctured and/or for a second set of systematic data is made. The new information is also stored in memory 44. The second stage of decoding then takes place with the more complete information; i.e., the previously punctured information is combined with the new stage of information and decoded.

FIG. 4 is a flow chart illustrating turbo-coding at the transmitter end according to an embodiment of the present invention. In step 60, the first (or next) information block is provided to the transmitter. Step 62 involves generating and storing the stage one information through stage N bits. Stage i bits are transmitted in step 64. After the receiver determines whether there has been a packet transmission error, an indication of same is given to the transmitter in step 66. If positive acknowledgment (i.e., an indication of no error) is given, the process returns to step 60 wherein the next information block is provided to the transmitter. If an error is indicated (i.e., no positive acknowledgment), then the transmission stage i is incremented, and the process returns to step 64. The process continues by incrementing the information stage one until positive acknowledgment is made.

FIG. 5 is a flow chart illustrating staged turbo-decoding, i.e., at the receiver end, according to an embodiment of the present invention. In step 70, the decoding stage i is set to one (1). In step 72, data samples are received, and in step 74, the received data samples are stored in memory. Turbo-decoding is performed in step 76, and a determination of a packet error is made in step 78. If not, then positive acknowledgment is made to the receiver in step 80. However, if a packet error is indicated in step 78, then the turbo-decoding stage i is incremented in step 82. A test is made in step 84 to determine whether a predetermined limit on the number of turbo-decoding stages (max) has been reached. If so, then a request to restart the turbo-decoding process is made in step 86. Otherwise, a

request for stage i turbo-decoding is made in step 88, and the process returns to step 72.

While the preferred embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions will occur to those of skill in the art without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

WHAT IS CLAIMED IS:

1. A method for turbo-coding in a communications system, comprising:

turbo-encoding source information using a parallel concatenation of first and second convolutional codes, the step of turbo-encoding comprising first and second encoding steps, the first encoding step applying the first convolutional code to the source information to provide a first group of code bits, the second encoding step applying the second convolutional code to the source information after interleaving the source information to provide a second group of code bits;

puncturing the first and second groups of code bits;

storing the punctured first and second groups of code bits in memory;

transmitting the first and second groups of non-punctured code bits to a receiver via a channel;

storing data samples corresponding to the first and second groups of non-punctured code bits in memory;

turbo-decoding the data samples corresponding to the first and second groups of code bits in at least two decoding stages and determining whether the transmitted code bits have been received in error;

if a transmission error is detected, maintaining the data samples corresponding to the first and second groups of non-punctured code bits in memory and transmitting at least a predetermined portion of the stored punctured code bits to the receiver, and then turbo-decoding in at least two stages by combining the data samples corresponding to the first and second groups of

non-punctured code bits with data samples corresponding to the transmitted punctured code bits.

2. The method of claim 1 wherein the step of puncturing comprises deleting code bits according to a predetermined puncturing pattern, and the step of turbo-decoding comprises a depuncturing function for inserting neutral values for the punctured bits.

3. The method of claim 1 wherein the first and second convolutional codes comprise systematic convolutional codes.

4. The method of claim 3 wherein the step of puncturing comprises transmitting a single copy of the first and second code bits, which copy is used in each turbo-decoding stage.

5. The method of claim 1 wherein the step of determining whether the code bits have been received in error comprises a 16-bit cyclic redundancy check code.

6. A communications system, comprising:

a transmitter comprising:

a turbo-encoder for turbo-encoding source information, said turbo-encoder comprising a parallel concatenation of first and second convolutional codes, the turbo-encoder applying the first convolutional code to the source information to provide a first group of code bits, and applying the second convolutional code to the source information after interleaving the source information to provide a second group of code bits;

a puncturing unit for puncturing the first and second groups of code bits;

memory for storing the punctured first and second groups of code bits;

said transmitter transmitting the first and second groups of non-punctured code bits via a channel to a receiver;

the receiver comprising:

memory for storing data samples corresponding to the first and second groups of non-punctured code bits;

a turbo-decoder for turbo-decoding the data samples corresponding to the first and second groups of code bits in at least two decoding stages and determining whether the transmitted code bits have been received in error; upon detection of a transmission error, the turbo-decoder maintaining the data samples corresponding to the first and second groups of non-punctured code bits in memory and requesting transmission of at least a predetermined portion of the stored punctured code bits to the receiver, the turbo-decoder then turbo-decoding in at least two stages by combining the data samples corresponding to the first and second groups of non-punctured code bits with data samples corresponding to the transmitted punctured code bits.

7. The system of claim 6 wherein the puncturing unit deletes code bits according to a predetermined puncturing pattern, and the decoder inserts neutral values for the punctured bits.

8. The system of claim 6 wherein the first and second convolutional codes comprise systematic convolutional codes.

9. The system of claim 6 wherein the puncturing unit transmits a single copy of the first and second code bits, which copy is used in each turbo-decoding stage.

10. The system of claim 6 wherein the decoder determines whether the code bits have been received in error by using a 16-bit cyclic redundancy check code.

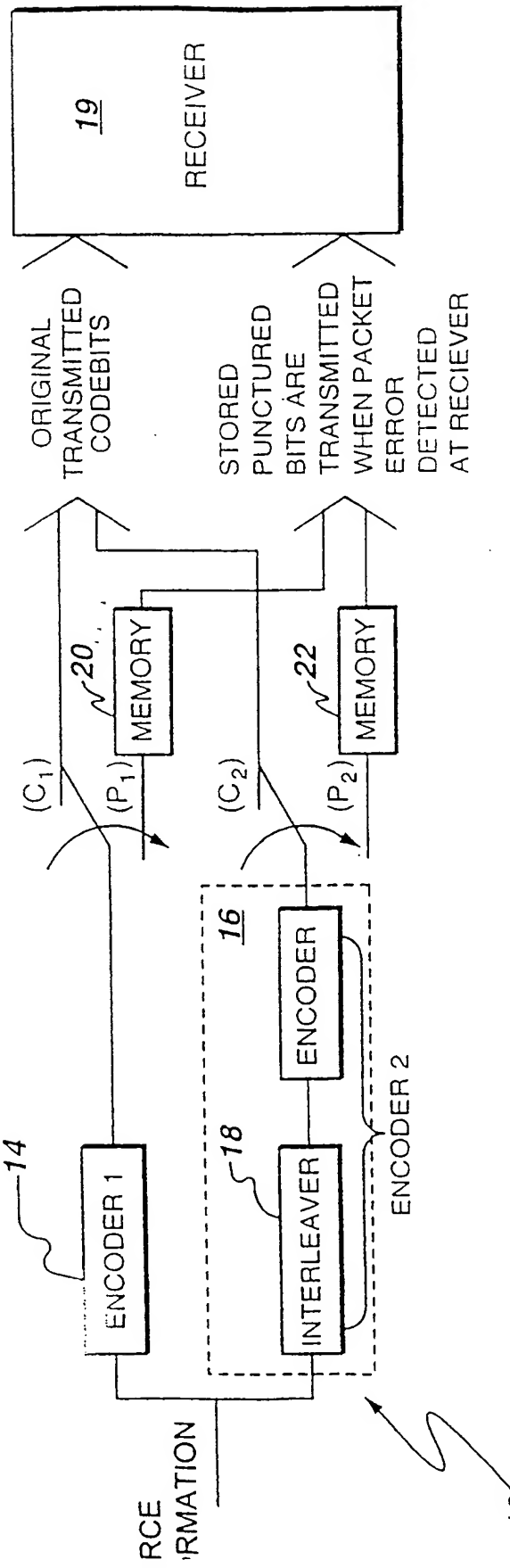

19
RECEIVER
ORIGINAL TRANSMITTED CODEBITS
STORED PUNCTURED BITS ARE TRANSMITTED WHEN PACKET ERROR DETECTED AT RECIEVER
20
MEMORY
22
MEMORY
(C_1)
(P_1)
(C_2)
(P_2)
16
ENCODER
18
INTERLEAVER
14
ENCODER 1
ENCODER 2
12

fig. 1

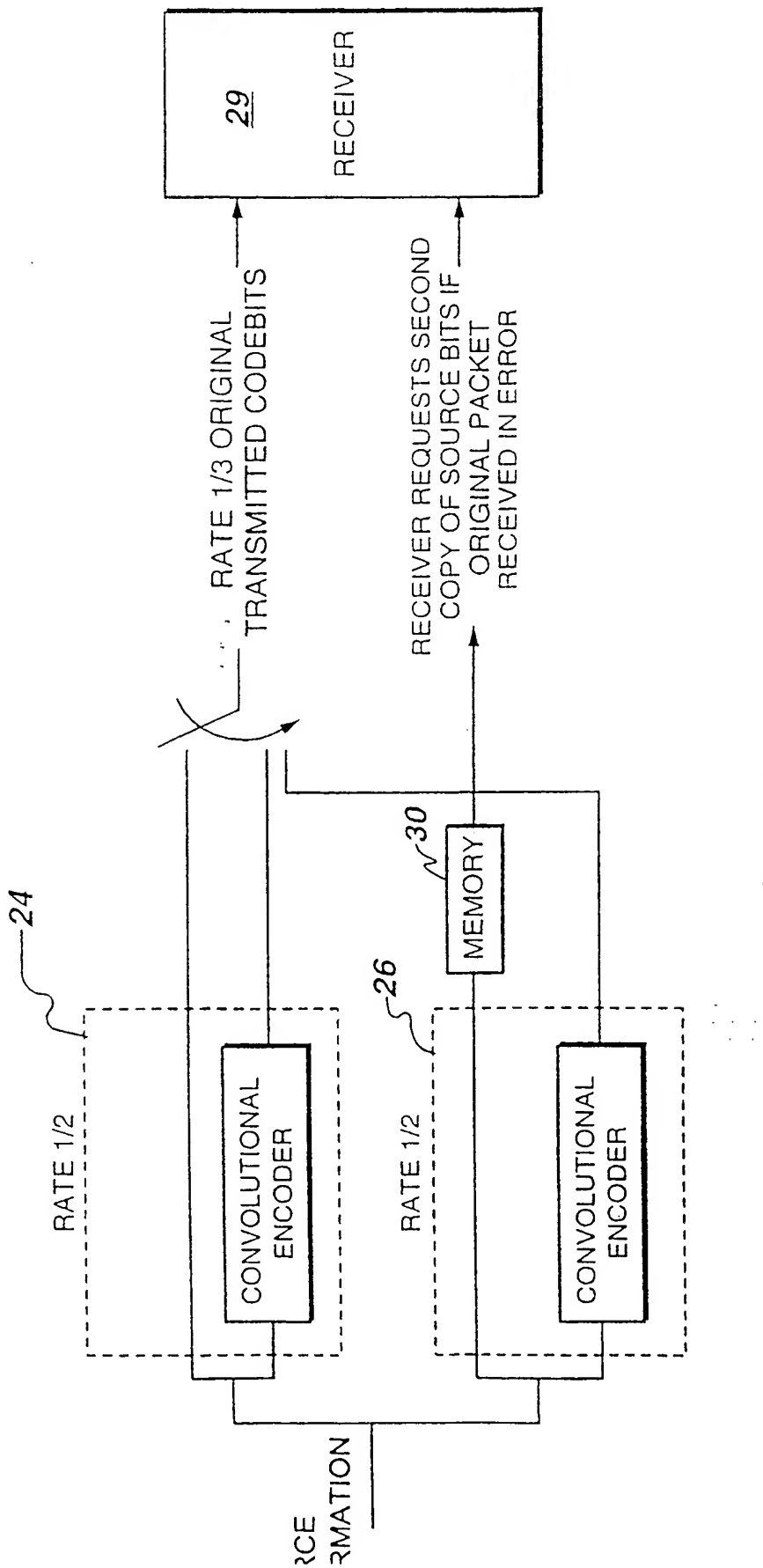

29
RECEIVER
RATE 1/3 ORIGINAL TRANSMITTED CODEBITS
RECEIVER REQUESTS SECOND COPY OF SOURCE BITS IF ORIGINAL PACKET RECEIVED IN ERROR
30
MEMORY
24
26
RATE 1/2
CONVOLUTIONAL ENCODER
RATE 1/2
CONVOLUTIONAL ENCODER
RCE
RMATION

fig. 2

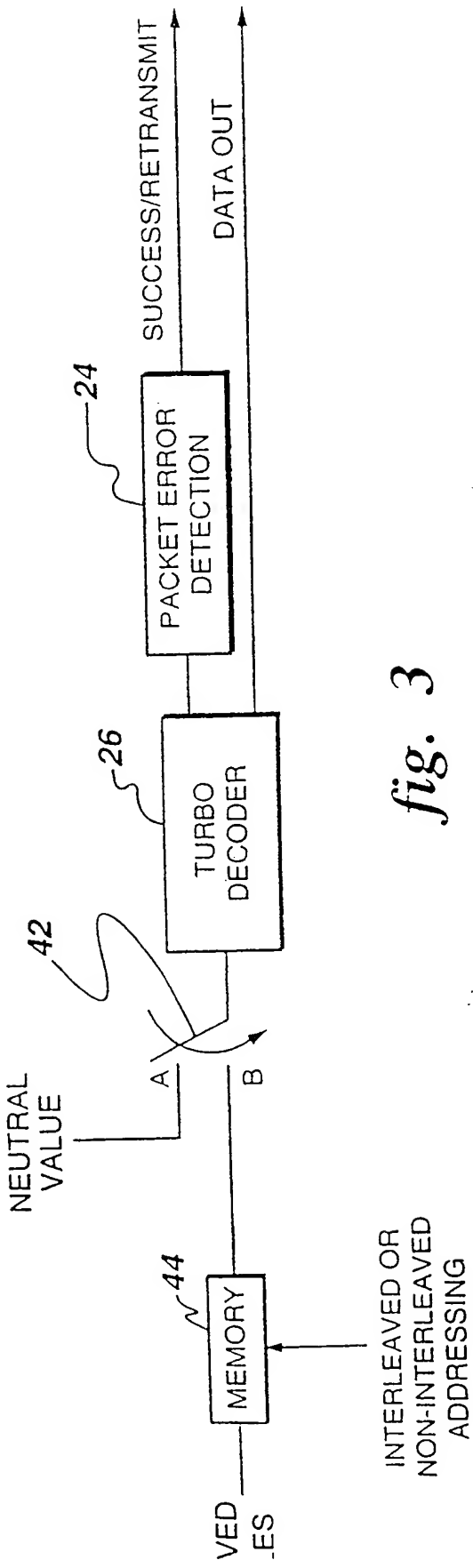

SUCCESS/RETRANSMIT
DATA OUT
24
PACKET ERROR DETECTION
26
TURBO DECODER
42
A
B
NEUTRAL VALUE
44
MEMORY
INTERLEAVED OR NON-INTERLEAVED ADDRESSING
VED
ES

fig. 3

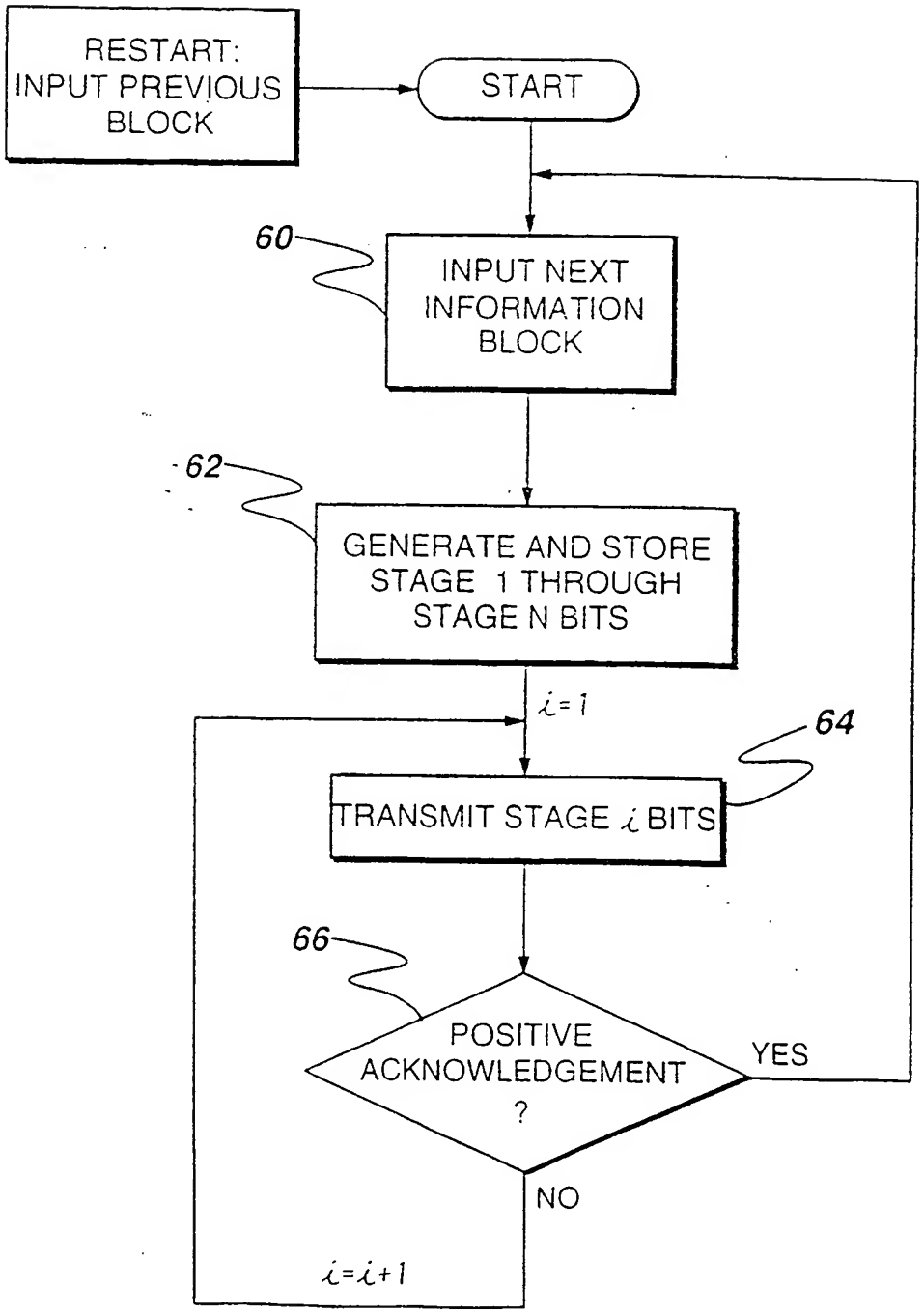

RESTART: INPUT PREVIOUS BLOCK
START
60
INPUT NEXT INFORMATION BLOCK
62
GENERATE AND STORE STAGE 1 THROUGH STAGE N BITS
i=1
64
TRANSMIT STAGE i BITS
66
POSITIVE ACKNOWLEDGEMENT ?
YES
NO
i=i+1

fig. 4

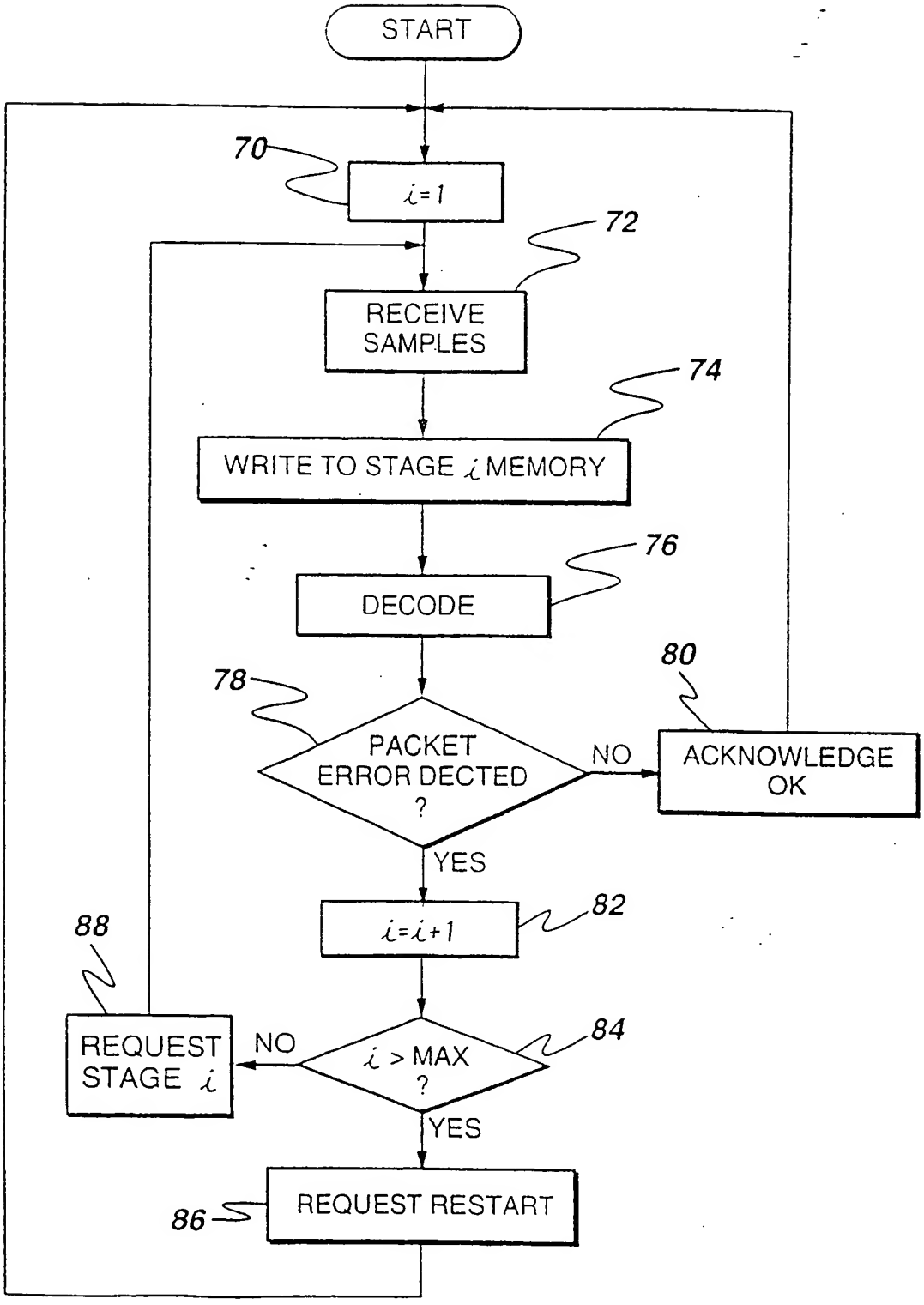

START
70
i=1
72
RECEIVE SAMPLES
74
WRITE TO STAGE i MEMORY
76
DECODE
78
PACKET ERROR DECTED ?
NO
80
ACKNOWLEDGE OK
YES
82
i=i+1
84
i > MAX ?
NO
88
REQUEST STAGE i
YES
86
REQUEST RESTART

fig. 5

INTERNATIONAL SEARCH REPORT

Inter. ..onal Application No
PCT/US 98/07348

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H03M13/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 511 141 A (FRANCE TELECOM ;TELEDIFFUSION FSE (FR)) 28 October 1992 see the whole document ---	1,3.6,8
A	NARAYANAN K R ET AL: "A NOVEL ARQ TECHNIQUE USING THE TURBO CODING PRINCPIPLE" IEEE COMMUNICATIONS LETTERS, vol. 1, no. 2, March 1997, pages 49-51, XP000687091 see the whole document ---	1,5,6,10
A	WO 96 24999 A (FRANCE TELECOM ;TELEDIFFUSION FSE (FR); DOUILLARD CATHERINE (FR);) 15 August 1996 ---	
A	DE 195 21 327 A (SIEMENS AG) 19 December 1996 ---	
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 August 1998	07/09/1998

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040 Tx. 31 651 epo nl

Authorized officer

INTERNATIONAL SEARCH REPORT

Inter ..ional Application No
PCT/US 98/07348

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	DIVSALAR D ET AL: "TURBO CODES FOR PCS APPLICATIONS" COMMUNICATIONS - GATEWAY TO GLOBALIZATION. PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, SEATTLE, JUNE 18 - 22, 1995. vol. VOL. 1, 18 June 1995, pages 54-59, XP000532968 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS	

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte. ional Application No
PCT/US 98/07348

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0511141 A	28-10-1992	FR 2675971 A	30-10-1992
		DE 69215743 D	23-01-1997
		DE 69215743 T	10-07-1997
		EP 0735696 A	02-10-1996
		US 5446747 A	29-08-1995
WO 9624999 A	15-08-1996	FR 2730370 A	09-08-1996
		EP 0808538 A	26-11-1997
DE 19521327 A	19-12-1996	NONE	